

A Real Options Approach to the Valuation of an Investment in Eucalyptus

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Abstract

This paper models optimal tree harvesting decisions using real options theory. In the problem considered, we must find the optimal eucalyptus harvesting timing in order to maximize the expected cash flow. The following specificities of the eucalyptus forest must be incorporated into our model: (i) trees younger than seven years old do not fit the industrial requirements of the pulpwood producers; (ii) trees older than fifteen years have a diameter that is too large for its industrial processing; and (iii) eucalyptus trees allow for two rotations, since the trees planted at the beginning of the project are suitable for two cuts. After the first cut the eucalyptus trees grow again, allowing for a second cut without replantation. Options path dependency is then observed, since the moment of exercise of the first option determines the time interval in which the second may be exercised. In addition, we also consider the option to abandon project and the option to convert land to another use. The option value is estimated by solving a dynamic programming model. The basic idea is to approximate the price by a binomial distribution and then establish a discrete-valued binomial lattice of possible future selling price values. Results are reported for a case study in the Portuguese eucalyptus forestry.

Key words. Forestry Investments, Real Options, Binomial Lattice, Dynamic Programming.

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1 Introduction

In the past few years large investments in the paper industry have been made in Portugal, which lead to an increase in the demand for raw materials and inputs to the paper production process. Hence, a growth in the forest area dedicated to the production of eucalyptus globulus, which is unanimously considered to be the tree species whose wood seems to be most suitable for paper production was observed. The number and size of investment projects (and the land used) in the production of eucalyptus globulus, as an input to the paper industry, has increased largely. However, as most investments in natural resources, these projects are not simple to undertake since optimal investment decisions tend to be far from obvious. This happens, due to the flexibility and uncertainty that characterize such decisions.

Traditionally, forestry investment decisions have been analyzed by using Discounted Cash Flow (DCF) techniques. Given their inability to account for flexibility, these approaches tend to systematically undervalue investments. DCF techniques are based on the assumption that future cash flows follow a constant pattern and can be accurately predicted. The project uncertainty, which may arise from the uncertainty about costs, selling prices, weather and legal conditions and flexibility, given to managers to react to changing conditions, is dealt with only superficially (Morck, Schwartz & Stangeland 1989). Another disadvantage of DCF is that it is linear and static in nature. It also assumes the project to be either irreversible or if reversible only decisions of now-or-never are allowed (Dixit & Pindyck 1994). Net Present Value (NPV) takes the project risk into consideration by discounting expected cash flows to the present moment. Using this decision process, all projects with positive NPV are undertaken, as they provide an “effective” growth in the wealth of the investor (or market value of the firm). The NPV, by not accounting for managerial flexibility, provides an underestimate of the project value, relative to real options. Therefore, when there is an option element in an investment, traditional DCF methods may result in wrong project valuation and hence inadequate decisions, see e.g. Pindyck (1991) and Dixit & Pindyck (1994).

Only in the seventies applications to natural resources management have been known (Henry 1974, Arrow & Fisher 1974). Traditionally, studies addressing real options in a forest context have applied a single option approach (Malchow-Møller, Strange & Thorsen 2004). However, this study goes beyond since we consider two rotations. Therefore, we have to decide when to harvest having in mind that a second harvest is possible. In addition, we also consider other options such as land conversion to another use and project abandonment. In this work, the main objective is to develop a methodology that allows for the valuation of the investment in eucalyptus forest for paper pulp production, considering the managerial flexibility inherent to the process. We apply real options to value a forestry investment. Results are provided

for a case study involving the investment in eucalyptus pulp production for the Portuguese paper industry, one of the most developed in the world. In this case study, two scenarios are considered: one where eucalyptus wood is sold to pulp and paper companies (basis problem) and another where vertical integration is considered, i.e. wood is processed into white paper pulpwood, which is then sold (extended problem).

2 Literature Review

In eucalyptus forest investments, the starting point is that the owner of the forest holds a call option¹, i.e. an option to buy timber at an exercise price given by the cost of cutting the timber. The forest option is similar to what in the finance literature is called an American option², since it can be exercised at any moment in a given time interval. This interval is given by the period during which the wood is suitable for pulp and paper production.

Up to date, not many studies have addressed forestry investments using a real options perspective. Morck et al. (1989) developed a contingent claims analysis of a long-term investment in renewable resource investments. Their model values a forestry lease and determines the optimal timing to harvest the timber. The value of the lease is considered to be the value of an option to cut down the trees at the best possible timing. The timber selling price and the inventory of timber are stochastic processes that follow geometric brownian motions. Zinkhan (1991) proposes a Black-Scholes type of approach for the valuation of the land use conversion option when valuing timberlands. The conversion option represents the ability of the timberland owner to convert the land use from timber to some other alternative use and was modelled as an European option rather than an American one. In the work by Bailey (1991) a model is proposed to value an agricultural producer considering optimal shutting and reopening and volatile output and demand. However, in what concerns forestry, the model is built only for productive trees with periodical (e.g. annual) harvest. This characteristic of the model makes it useless for our purpose of valuation of forestry investment in eucalyptus for paper pulp production, where after two cuts the asset is “worthless” for the paper industry. Abildtrup & Strange (1999) analyze the decision to convert a natural or semi-natural forest into Christmas tree production, when groundwater contamination is irreversible and future returns on non-contaminated groundwater resources and Christmas tree production are uncertain. It is concluded that conventional

¹An option is the right, but not the obligation, to take some action in the future under specified terms. A call option gives the holder the right to buy a stock at a specified future date (maturity) by a specified price (exercise or strike price). This option will be exercised (used) if the stock price on that date exceeds the exercise price.

²An American option differs from a European option since the former can be exercised at any time up to the expiration date, while the latter allows for exercise only at expiration date.

expected NPV analysis may not lead to an optimal decision rule. It is shown how the option to postpone conversion and acquire new information should be included. Yin (2001) discusses harvest timing, land acquisition, and entry decisions combining forest level analysis and options valuation approach.

Most of the studies addressing real options in the forest investment context have applied a single option approach. However, exceptions can be found in literature. Some authors consider additional problem features, while others consider more than a single option. For example, Malchow-Mollera et al. (2004) include temporal and spatial arrangement of harvests. These authors consider that constraints upon harvesting options on adjacent forest stands are imposed and examine the optimal harvest rules under adjacency restrictions and uncertainty. They conclude that the costs of adjacency constraints tend to increase with uncertainty and that the optimal harvesting strategies become rather complex due to the involved stochastic variables. Duku-Kaakyire & Nanang (2004) developed a forestry investment analysis where four management options are considered: delay of reforestation, capacity expansion, investment abandonment, and a compound option obtained considering simultaneously all three previous options. The models developed are evaluated on a standard binomial lattice. The authors solve an example with which they show that DCF techniques value the investment as unprofitable, consequently rejecting it. Real options, however, show the investment to be highly valuable.

3 Problem Description

The investment decision under consideration must include four main options: the option to cut down the trees; the option to postpone or defer the trees harvesting until the price or quantity is favorable; the option to convert the land to another use; and the option to abandon the project. These options are all considered simultaneously.

In this work, the inventory of wood is considered to be a deterministic process, that follows a known growth pattern depending on the region under consideration, the time since last cut (or plantation), and the rotation. Also, an obviously very important factor for the decision making is the paper pulpwood selling price, since it determines the main positive cash flow. The price is stochastic and it is assumed to follow a geometric brownian motion. This is further discussed in Section 4.

The investment decisions

When the tree is mature, the landowner possesses the option to cut down the trees and receive the potential cash flow. On the other hand, such a decision may be postponed if price and/or

wood inventory conditions are not favorable. This option is similar to a financial option on a stock, where the underlying asset is the amount of wood in the land and the strike price is the cost of cutting the trees and logging the wood. However, the investment process in eucalyptus is normally composed of two rotations (production cycles). The trees planted at the beginning of the process are suitable for two cuts - after the first cut trees regrow, permitting a second cut without replantation. Regarding the timing of cut, the characteristics of the wood that could be extracted from trees which are up to 7 years old do not fit the requirements of the industrial producers of pulpwood. The same happens after 16 years of growth, when the diameter of the trees becomes too large for its industrial processing and the fiber in the wood is not of the required standards. The investor in eucalyptus holds two interdependent options to cut down the trees, as the time of exercise of the first option determines the time window during which the second option may be exercised. Although the frame of the time window is known to be 9 years, the time window temporal location for the second cut option depends on the timing of the first cut. Furthermore, the expected payoff to be received is given by the sum of the first and second harvesting expected cash flows. Given the path dependency observed, the cash flow received from the second harvesting depends upon the timing of the first harvesting. This dependency leads to a multiplicity of possible paths and strategies, as can be seen in the state transition diagram given in Figure 1. In this diagram we have represented the time t and the elapsed time since last cut or plantation x_t , with a 2-years step interval.

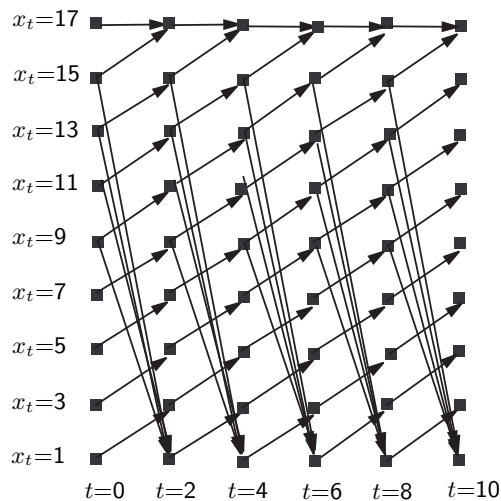


Figure 1: State transition diagram: 2-years step interval.

The cash flow to be received from harvesting the trees depends on the cutting period - since the quantity of wood, although known, evolves through time - and on wood market price and future value expectations. Moreover, the decision of cutting the trees in the first rotation must

consider not only the immediate cash flow, but also the expectation of the cash flow from the second rotation.

In our analysis, the eucalyptus forest investor is assumed to hold the land. Therefore, at any moment in time holds the option to abandon the project and put it aside, or receive an estimated value from converting to an alternative use. Activities like tourism and hunting have increased the demand for forest land and hence, its value. This alternative value (or capacity to abandonment without a loss greater than the initial investment) must then be considered in the valuation of eucalyptus forest investment.

4 Methodology

The solution approach developed consists of a dynamic programming model which is evaluated on a discrete-valued lattice. The uncertainty of the underlying risky asset, wood or paper pulp selling price, is modelled through the use of a standard binomial lattice. In this approach, the stochastic variable (the selling price in our case) is assumed to be governed by a geometric diffusion, which implies that at each period there is only one constant growth/decay rate. If this is assumed, a natural way of obtaining a valued-lattice for the stochastic variable is to discretize it through a standard binomial lattice, see Figure 2.

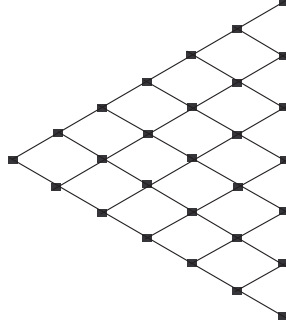


Figure 2: A lattice discretizing selling price.

A node of price value P_t^i can lead to two nodes with their values being given by $P_{t+1}^{i+1} = uP_t^i$ and $P_{t+1}^{i-1} = dP_t^i$ with probability p and $q = 1 - p$, respectively. The probability of reaching each of these nodes is the usual equivalent martingale measure used in the binomial option pricing model of Cox, Ross & Rubinstein (1979):

$$p = \frac{(1 + r_f) - d}{u - d} \quad \text{and} \quad q = 1 - p, \quad (1)$$

where r_f is the risk free interest rate over the interval Δt , $u = \exp(\sigma\sqrt{\Delta t})$, and $d = \exp(-\sigma\sqrt{\Delta t})$.

It should be noticed that, as $\Delta t \rightarrow 0$ the parameters of the multiplicative binomial process converge to the geometric brownian motion.

4.1 Decision and state variables

The selling price variable P_t^i is modelled as a stochastic variable, which follows a binomial process, as explained.

In terms of decisions, as previously described, there are basically three types: to cut the trees, delay trees cutting, and abandon project or convert land to another usage. Hence, we define a decision variable D_t^i that may assume three values according to the decision taken at time t and state (price index expectation) i .

$$D_t^i = \begin{cases} 1, & \text{if trees are cut,} \\ 2, & \text{if cut is postponed and investment maintained,} \\ 3, & \text{if project is abandoned or land converted to another use.} \end{cases}$$

The inventory of wood is considered to be a deterministic process, following a known growth pattern according to the considered region, the time since last cut (or plantation), and the rotation. The evolution of the time since the first cut (or plantation) x_t is modelled as:

$$x_{t+1} = \begin{cases} 2, & \text{if } D_t^i = 1, \\ x_t + 1, & \text{if } D_t^i = 2, \end{cases}$$

and initialized as $x_1 = 1$. In the second rotation x_t is initialized as 2, rather than 1 which is the case for rotation 1, since the trees are already there and thus, do not need to be planted. If the decision is to abandon the project or convert land to another use then the project ends.

Regarding the inventory of wood, recall that the wood obtained from trees having up to 7 years of growth, as well as from trees with more than 16 years of growth, does not meet paper pulp industrial requirements. Let $tc_{min} = 8$ and $tc_{max} = 16$ be, respectively, the minimum and maximum time from plantation (or first cut) for the trees to be suitable for paper production. Let $SQ(x_t, i)$ be the inventory of wood that can be sold to paper pulp production.

$$SQ(X_t, t) = \begin{cases} 0, & \text{if } x_t < tc_{min} \text{ or } x_t > tc_{max}, \\ Q_1(x_t), & \text{if } x_t = t, \\ Q_2(x_t), & \text{if } x_t < t. \end{cases}$$

where $Q_1(x_t)$ and $Q_2(x_t)$ are the inventory of wood extracted from cutting the trees which have been growing for x_t years at rotation 1 and rotation 2, respectively.

4.2 Dynamic programming model

In each period, the forest investor must decide whether the forestry investment is going to be kept or not. Since both for project abandonment and land use conversion options only a lump sum is received, no subdivision is considered regarding these options.

Harvesting the trees yields the owner a revenue from the selling of the wood but also involves costs K incurred with cutting, peeling, and transporting the wood. Therefore, at period t , given the elapsed time since last cut or plantation x_t and the price expectation index i , the net revenue π obtained if the cutting option is exercised is given by

$$\pi(x_t, i, t) = (P_t^i - K) \times SQ(x_t, t) - K. \quad (2)$$

As said before, and in order to allow for earlier exercise, the valuation procedure begins at the last stage and works backwards to the initial moment. At the final lattice nodes, i.e. at the end of the project life $t = T$, all terminal nodes for each of the possible selling price values and elapsed time since last cut values are computed. For each of these nodes the project value is then given by the largest of (i) the final revenue plus residual value if a harvesting decision is still possible and exercised or (ii) the residual value. Here, by residual value R we mean the maximum between land value as it is and land conversion value.

$$V(x_T, i, T) = \max \begin{cases} \pi(x_T, i, T) + R, \\ R. \end{cases} \quad (3)$$

The project value at each intermediate lattice node is computed by performing a backward induction process. The project value at intermediate steps is used to compute the project value at previous steps by using risk neutral probabilities. The decision made at any period (and state variable) has implications not only on the cash flow of the current period but also on the expected cash flow of future periods. Therefore, the optimal project value is obtained by maximizing the sum of the current period's net revenue with the optimal continuation value considering all possible decisions. The optimal project value at period t , given the elapsed time since last cut or plantation x_t and the price expectation index i , is then given by

$$V(x_t, i, t) = \max_{D_t^i} \begin{cases} \pi(x_t, i, t) + \frac{pV(x_{t+1}, i+1, t+1) + (1-p)V(x_{t+1}, i-1, t+1)}{1+r_f}, & \text{if } D_t = 1, \\ \frac{pV(x_{t+1}, i+1, t+1) + (1-p)V(x_{t+1}, i-1, t+1)}{1+r_f}, & \text{if } D_t = 2, \\ R. & \text{if } D_t = 3, \end{cases} \quad (4)$$

where $\pi(x_t, i, t)$ is the net revenue from the selling of the wood, r_f is the real risk free interest rate, p is the risk neutral probability of an upward movement in the binomial price, and R is the abandonment or conversion to another use value, whichever is larger.

The estimated project net value is then given by $V(1, 1, 1)$ minus the initial investment³. Furthermore, the solution to this model also provides an optimal decision strategy for the forest manager.

5 Case study

In this section, we start by giving a brief characterization of the Portuguese forest sector. Secondly, we describe the case study to which our model is to be applied, and end by presenting the results obtained.

5.1 Brief characterization of the Portuguese forest sector

Portugal, due to its natural characteristics, possesses unique natural and ecological conditions for forestry production, which only recently have started to be methodologically and professionally managed.

Regarding productivity, the net annual increment per hectare in forests for wood supply is about 4.6 m³/ha/year for *pinus pinaster* and 9 m³/ha/year for *eucalyptus globulus*, which is relatively small. This is mainly due to poor forest management and lack of modern techniques. Professional management and planning could bring a productivity increase of over 20% (Mendes 2004). Nevertheless, the average production of wood per year and hectare is much higher in Portugal than in the Scandinavian countries, which are known for their forestry products. In addition, the average length of the forestry production cycle is much shorter in Portugal (Goes 1991).

The *eucalyptus globulus*, the main sub-species in our country and the one that possesses the best characteristics for paper production, is a fast growing tree. Originally biologically adapted to the poor soils of the Australian continent, in southern Europe, and Portugal in particular, this species grows very rapidly. Normally, the *eucalyptus* are cut with an age of 12 years and used to produce pulpwood, providing cellulose fibers that have remarkable qualities for the production of high quality paper.

Forest and forest related industries are a key sector in the Portuguese economy, generating wealth and employment. The modernization of this sector can be a source of competitive advantage for the country, given the favorable ecological and natural conditions. Due to the development of the paper production industries, and the natural characteristics of the species, *eucalyptus globulus* has shown to be a key player in the sector, with a huge wave of investment

³The initial investment is considered to be given by the land acquisition costs, the plantation costs, and the cost of a maintenance contract for the full length of the project.

in the species in the last decades.

5.2 Data and parameters

The initial investment: plantation and maintenance costs

We assume that the investor contracts all expected operations to a specialized firm at the start of the investment and pays the contract in advance. The operations and their present value costs add up to 3212 euros per hectare, from which 1712 euros correspond to the plantation and the 2 rotations (24 years expected) maintenance contract, and 1500 euros correspond to the acquisition cost of 1 hectare of land.

Wood and white paper pulpwood prices

The price of wood in the basis problem and the price of white paper pulpwood in the extended problem are assumed to follow a binomial stochastic process, as previously explained. Recall that, in this study two scenarios are considered. The basis problem considers that the eucalyptus forest is owned by a forest investor, and that its wood is sold to pulp and paper companies. The extended problem considers that the eucalyptus forest is owned by the paper industry and that the wood is processed into white pulp, which is then sold. We use 2002 prices, which are 45 euros per cubic meter of peeled eucalyptus wood and 500 euros per cubic meter of white paper pulp (*Aliança Florestal* 2002). The prices volatility was extracted from the time series of prices (FAO – Food and Agricultural Organization of the United Nations, CELPA – Associação da Indústria Papeleira), considering constant prices of 2002, using the consumer price index as deflator (*INE – Infoline* 2001). The extracted volatility corresponds to the volatility of returns of the three-years moving average of prices. This average was calculated in order to smooth the price series, as jumps in prices were periodical (3 year intervals between jumps). The price volatility measured by the standard deviation has been computed to be 0.07173 for wood and 0.10687 for white pulpwood.

Wood and white paper pulpwood quantities

In order to compute the quantities of available wood per ha of eucalyptus forest we have used the inventory model Globulus by Tomé, Ribeiro & Soares (2001). We have considered wood quantities for the three main Portuguese regions in what concerns eucalyptus investment: north central coast (region 1), central coast (region 2), and river Tejo valley (region 3). For each region and rotation we consider different tree growth patterns. In the extended problem, which uses pulpwood valuation, it has been considered that 1 cubic meter of wood can potentially produce

0.358 cubic meters of pulp. Thus, we need about 3.07 cubic meters of wood in order to be able to produce 1 ton of white pulp, which corresponds to approximately 1.1 cubic meters of white pulp (*Aliança Florestal* 2002).

The exercise price for the cutting option K

The exercise price of the cutting option is given by the costs incurred in cutting the trees, peeling the wood, and transporting it to the factory. Considering constant prices of 2002, the total cost is estimated to be 22.5 euros per cubic meter of wood (*Aliança Florestal* 2002). When considering the extended problem, which takes into account transformation into white pulp, the cost of this transformation must also be taken into consideration. The industrial processing cost is approximately 320 euros per ton of white pulpwood⁴ (200 euros of variable costs and 120 euros of fixed costs). The cost of cutting, peeling and transporting the wood necessary for a ton of white paper pulp is 69.14 euros. Therefore, a ton of white paper pulp costs 389.14 euros to transform. As 1 ton of white paper pulp corresponds to 1.1 cubic meters, the cost of processing 1 cubic meter of white paper pulp is then 353.76 euros (Portucel Setúbal 2002).

The risk free interest rate r_f

As we are working with real prices from the year 2002, we have considered a real risk free interest rate of 3%. This value was chosen through the observation of the Euro yield curve (average nominal risk free interest rate of 5% for long term investments such as the eucalyptus) and the 2% expected inflation in the euro area (Eurostat).

The abandonment and Conversion to another land use value R

In each time step, the investor possesses the option to abandon the investment project, putting the land aside and/or receiving the market price for agricultural and forest land.

In other situations, the investor may convert the land use into other activities, e.g. tourism, hunting or real estate development. In this work, we consider both situations. We assume that demand may exist for the land as it is, or for the land to be converted to another use. Several possible values for the conversion value R are considered, from the situation where no value is given to the land due to lack of demand, to situations of high conversion values that may arise, for example, due to real estate speculation.

⁴This value was obtained through the analysis of the operating costs of the paper pulpwood companies and their installed capacity, and also through inquiries to experts.

6 Results

In this section, we specify the computational experiments conducted as well as the results obtained. All experiments have been performed using three regions in continental Portugal: 1 – north central coast, 2 – central coast, and 3 – river tejo valley.

The results are divided into two sections, one regarding the dynamic programming model discussed in the previous section and another regarding the application of the harvesting strategies obtained to randomly generated data sets. In the first section, we report on the results obtained by applying the aforementioned dynamic programming model to the basis and extended problems. Recall that the basis problem considers the forest to produce wood, which is cut, peeled, and transported to the factories. Regarding the extended problem, we consider that it also includes the wood processing into white paper pulp, which is then sold. In the second section, we present results regarding the implementation of the optimal strategies provided by the dynamic programming model to both the basis and the extended problem. In order to do so, we randomly generate sets of price data, to which we apply these optimal strategies. The application of these strategies to the randomly generated data only considers the fact that price movements are upwards or downwards, disregarding the magnitude of the movement.

A – Results for the basis and extended problem

To start with, and in order to have a standard project value, we compute the value of the project considering that cuts are performed at years 12 and 24 respectively, since this is the common practice. The price values used are the expected value of the price at years 12 and 24. Several possible values are considered for the land residual value. This valuation is in nature a Net Present Value (NPV) approach. The cut timing strategy considered has been observed to be the most common among eucalyptus forest managers.

The results, reported in Table 1, are computed for the three above mentioned regions, as

$$\sum_{k=1}^{12} p_{k,12} \frac{\pi(12, k, 12)}{(1 + r_f)^{11}} + \sum_{k=1}^{24} p_{k,24} \frac{\pi(12, k, 24)}{r_f^{23}} + \frac{R}{(1 + r_f)^{23}}, \quad (5)$$

where $p_{k,12}$ and $p_{k,24}$ are the probabilities of having a price index k at the twelfth and twenty

fourth years, respectively and are computed as

$$p_{k,12} = \begin{cases} p^{11}, & \text{if } k = 1, \\ (1 - p)^{11} & \text{if } k = 12, \\ 2 \cdot p^{12-k} \cdot (1 - p)^{k-1}, & \text{otherwise.} \end{cases} \quad (6)$$

$$p_{k,24} = \begin{cases} p^{23}, & \text{if } k = 1, \\ (1 - p)^{23} & \text{if } k = 24, \\ 2 \cdot p^{24-k} \cdot (1 - p)^{k-1}, & \text{otherwise.} \end{cases}$$

Residual value	Basis problem			Extended problem		
	region 1	region 2	region 3	region 1	region 2	region 3
0	311	251	184	590	476	351
1000	818	758	691	1097	983	858
3000	1831	1772	1704	2110	1996	1871
5000	2845	2785	2718	3123	3009	2884
10000	5378	5318	5251	5657	5543	5418
15000	7912	7852	7785	8190	8076	7951
20000	10445	10385	10318	1724	10610	10485
25000	12979	12919	12852	13257	13143	13018
30000	15512	15452	15385	15791	15677	15552

Table 1: “Standard” Project value (NPV), for varying residual values.

In order to show that the postpone and abandonment/conversion options interact, we value the project considering (i) that only the harvesting and postponement options exist and (ii) that all options exist, see Tables 2 and 3. Furthermore, the project is valued considering several land residual values R .

For the results presented in Table 2, where only the harvesting and postponement options exist, the residual value R is only recovered at the end of the project. This happens, at time T or either whenever the two possible cuts have already been performed or no further cutting is allowed.

When considering all options the residual/conversion land value is obtained in the same conditions as above or whenever it is optimal to give up further harvesting. In the results reported in Table 3, we have considered that the value to be recovered is the residual value R , since a better comparison with the results obtained when considering only the harvesting and postponement options, is possible. It should be noticed that, by doing so we are considering an option that is no more than an abandonment option.

Residual value	Basis problem			Extended problem		
	region 1	region 2	region 3	region 1	region 2	region 3
0	15956	13081	8185	51295	42116	26030
1000	16368	13493	8597	51712	42533	26447
3000	17192	14317	9421	52547	43368	27282
5000	18016	15141	10245	53382	44203	28117
10000	20076	17202	12312	55470	46291	30205
15000	22137	19266	14437	57558	48379	32331
20000	24204	21349	16748	59646	50467	34484
25000	26291	23496	19390	61734	52566	36655
30000	28429	25789	22369	63839	54713	38841

Table 2: Project value considering harvesting and postponement options, for varying residual values.

The differences in valuation between the standard NPV approach typically used by the industry, and the options approaches here presented are clear. Under the NPV project, considering residual values up to three times the considered land acquisition price, the project would not be undertaken, as its value does not cover for the 3212 euros needed for the initial investment. The real options approach, due to the consideration of the flexibility in the management of the forest, allows for much higher values. In Tables 2 and 3, it can be observed that the real options valuation outputs clearly exceed the initial investment costs⁵. These values seem to be more consistent with the high profitability of the professional investments in forest.

Another main conclusion that can be drawn is that the different sources of flexibility clearly interact. However, the difference in valuation considering the presence of all options and only the main cutting options is only relevant if considering very high residual values. This does not come as a surprise, since we consider that the residual value is a fixed value in time. Given that we are discounting future cash flows, then the residual present value decreases with project time horizon. Furthermore, we are not considering a real land conversion value, which can often be much larger than the abandonment value.

Before comparing the results obtained for the basis problem and the extended problem, let us recall what these problems are. The basis problem represents the situation where the forest is considered to be privately owned, and the eucalyptus wood is sold to paper industry companies. The extended problem, however, considers that the forest investment and management

⁵Although in these cases, the initial investment might be larger than 3212 euros as this value has been obtained for a 24 years project life.

Residual value	Basis problem			Extended problem		
	region 1	region 2	region 3	region 1	region 2	region 3
0	15956	13081	8185	51295	42116	26030
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10000	20076	17202	12312	55470	46291	30205
15000	22137	19266	14437	57558	48379	32331
20000	24204	21349	16748	59646	50467	34484
25000	26291	23496	19390	61734	52566	36655
30000	28429	25789	22369	63839	54713	38841

Table 3: Project value considering all options, for varying residual values.

is vertically integrated into the paper industry production process. The value added by the ownership of forest land being in the hands of the pulp industries (or the value added through vertical integration) can be estimated through the difference between the project values for the basis and the extended problems, as given in Table 4.

Residual value	Harvest and postpone options			All options		
	region 1	region 2	region 3	region 1	region 2	region 3
0	35339	29035	17845	35339	29035	17844
1000	35344	29040	17850	35345	29040	17851
3000	35355	29051	17861	35359	29056	17866
5000	35366	29062	17872	35374	29070	17881
10000	35394	29089	17893	35410	29108	17908
15000	35421	29113	17894	35450	29140	17405
20000	35442	29118	17736	35467	29071	14611
25000	35443	29070	17265	35340	27684	11881
30000	35410	28924	16472	33979	24875	9248

Table 4: Project value differences between basis and extended problems, for varying residual values.

As it can be observed, the difference in project value is smaller when all options are considered and the abandonment value is large. This is expected, since in these cases the land abandonment value is larger than the project value for wood exploration and almost as large as project value for pulp exploration. Nevertheless, the value added through vertical integration

seems to be extremely high, and justifies the direct and indirect investment of paper industry companies, out of their core business of paper pulp production, into producing the inputs themselves. However, care should be taken in drawing conclusions since non negletable investments may be required for the vertical integration.

C – Applying the optimal strategies

In order to be able to find out how many years the trees are left to grow at each rotation we apply the optimal strategy provided by the dynamic programming model that considers all options, to randomly generated price data sets. By doing so, we are able to report not only on the project value but also on the number of years that trees are left to grow (for both rotations). The project value is compared to the one that would be obtained by the common practice of harvesting at years 12 and 24. Five data sets have been randomly generated according to the characteristics given in Table 5. The characteristics reported are relative to the price values used in the case study.

Data Set	Price values		
	minimum	maximum	average
1	80%	100%	80%
2	100%	100%	90%
3	100%	100%	100%
4	100%	100%	110%
5	100%	120%	120%

Table 5: Characteristics of the randomly generated data sets.

We report on the project value (value), the years at which harvesting takes place, for both rotations (rot1 and rot2), and when abandonment takes place (aban) if it does take place. These values have been obtained by applying the optimal strategies devised both for the basis and the extended problems. These results are provided for the 5 randomly generated data set types. We also report on the project value obtained by performing the harvest at years 12 and 24.

In Table 6 we report on the common practice project value (CPV) obtained by cutting at years 12 and 24 and by using the the all options dynamic programming model (value) for land residual values of 0, 5, 10, 20, and 30 thousand euros. As it can be seen, in most of the above situations the project is better when computed using the real options approach. Region 1, the north central cost, is the most appropriate area in the country for eucalyptus and thus, the most productive. Results for the other two regions are, however, similar.

The timing at which rotation 1 and rotation 2 cuts take place are reported in Table 7. In this

Region 1

Data Set	R=0		R=5000		R=10000		R=20000		R=30000	
	NPV	value	NPV	value	NPV	value	NPV	value	NPV	value
1	29619	33492	32153	35492	34686	37492	39753	41491	44820	45491
2	12920	13813	15453	15813	17987	17813	23053	21813	28120	25812
3	29479	48288	32013	50288	34546	52288	39613	56288	44680	43565
4	48615	34748	51148	36748	53682	38748	58749	42748	63815	46748
5	43898	46278	46431	48278	48965	50277	54032	54277	59098	58277
Average	32906	35324	35440	37324	37973	39324	43040	43323	48107	43979

Table 6: Project value for region 1 when decision strategies are applied to specific data sets.

table we also report the year at which the project is abandoned whenever abandonment indeed occurs. It should be noticed that the harvesting decisions typically take place after sixteen years

Region 1

Data Set	R=0		R=5000		R=10000		R=20000		R=30000		
	rot1	rot2	rot1	rot2	rot1	rot2	rot1	rot2	rot1	rot2	aban
1	16	31	16	31	16	31	16	31	16	31	0
2	16	31	16	31	16	31	16	31	16	31	0
3	16	31	16	31	16	31	16	31	16	0	30
4	16	31	16	31	16	31	16	31	16	31	0
5	16	31	16	31	16	31	16	31	16	31	0

Table 7: Cutting, postponement, and abandonment strategies for region 1 when decision strategies are applied to specific data sets.

of growth for both rotations. This corresponds to the maximum time growth allowed. Thus, it can be concluded that the cutting option is exercised almost always at maturity, which allows for the investor to take advantage of the full tree growth. This fact is inconsistent with the common practice of most forest producers. The urge to cash in the value of their eucalyptus wood, typically made at the 12th year seems to be not optimal.

7 Conclusions

In this work, we address the valuation of the investment in eucalyptus for the paper pulp industry by using real options theory. The modelling of the eucalyptus forest investment decisions using

real options theory allows valuation results more consistent with the normal positive investment outcomes than the ones obtained using traditional valuation techniques. The interpretation of the two possible tree cuts as two exercise interdependent call options on the wood allows us to introduce managerial flexibility in the forest management process. The inclusion of the abandonment and conversion to another use options increases the closeness to the real decision process.

The evidence in this paper, through the application of the developed dynamic programming model to the eucalyptus investments in three Portuguese regions and for randomly generated situations, is consistent with the experts warnings of the under-valuation performed by traditional discounted cash flow techniques. A rationale for the vertical integration of paper pulp and wood production is also provided by the value added difference between the two problems considered.

It is also shown that typical cut timing decisions are not consistent with cash flow maximization. According to our model, cutting should be almost in all situations performed at the end of the time interval when wood is suitable for paper pulp production.

References

- Abildtrup, J. & Strange, N. (1999), ‘The option value of non-contaminated forest watersheds’, *Journal of Forest Policy and Economics* **1**, 115–125.
- Aliança Florestal* (2002), Technical Internal Report: www.alflorestal.pt.
- Arrow, K. & Fisher, A. C. (1974), ‘Environmental preservation, uncertainty and irreversibility’, *Quarterly Journal of Economics* **88**, 312–319.
- Bailey, W. (1991), ‘Valuing agricultural firms: An examination of the contingent claims approach to pricing real assets’, *Journal of Economic Dynamics and Control* **15**, 771–791.
- CELPA – (Associação da Indústria Papeleira), www.celpa.pt.
- Cox, J., Ross, S. & Rubinstein, M. (1979), ‘Option pricing: a simplified approach’, *Journal of Financial Economics* **12**, 229–263.
- Dixit, A. & Pindyck, R. S. (1994), *Investment under uncertainty*, Princeton University Press, Princeton, New Jersey.
- Duku-Kaakyire, A. & Nanang, D. M. (2004), ‘Application of real options theory to forestry investment analysis’, *Journal of Forest Policy and Economics* **6**, 539–552.

- FAO – (Food and Agricultural Organization of the United Nations), www.fao.org.
- Goes, E. (1991), A floresta portuguesa: sua importância e descrição das espécies de maior interesse, Company report, Portucel.
- Henry, C. (1974), ‘Option values in the economics of irreplaceable assets’, *Review of Economic Studies* **41**, 89–104.
- INE – Infoline (2001), Instituto Nacional de Estatística: www.ine.pt.
- Malchow-Møller, N., Strange, N. & Thorsen, B. J. (2004), ‘Real-options aspects of adjacency constraints’, *Forest Policy and Economics* **6**, 261–270.
- Mendes, A. (2004), Portuguese forests, Country report delivered to the EFFE project - evaluating financing of forestry in Europe, Porto: Portuguese Catholic University, Faculty of Economics and Management.
- Morck, R., Schwartz, E. & Stangeland, D. (1989), ‘The valuation of forestry resources under stochastic prices and inventories’, *Journal of Financial and Quantitative Analysis* **24**(4), 473–487.
- Pindyck, R. S. (1991), ‘Irreversibility, uncertainty, and investment’, *Journal of Economic Literature* **29**(3), 1110–1148.
- Portucel Setúbal (2002), Technical Internal Report: www.portucelsoporcel.com.
- Tomé, M., Ribeiro, F. & Soares, P. (2001), O modelo glóbulus 2.1, Technical report, Grupo de Inventariação e Modelação de Recursos Naturais, Departamento de Engenharia Florestal, Instituto Superior de Agronomia, Universidade Técnica de Lisboa.
- Yin, R. (2001), ‘Combining forest-level analysis with options valuation approach – a new framework for assessing forestry investment’, *Forest Science* **47**(4), 475–483.
- Zinkhan, F. (1991), ‘Option pricing and timberlands land-use conversion option’, *Land Economics* **67**, 317–325.